



High resolution data assimilation experiment of Myanmar cyclone Nargis based on Local Ensemble Transform Kalman Filter

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Introduction

Nargis was a severe tropical cyclone (TC) that formed in the Bay of Bengal in April 2008 and made landfall in the Irrawaddy delta, resulting in massive damage and loss of life in Myanmar. After forming, Nargis followed the northwest direction until April 30th 2008 then turned to the east direction, intensified rapidly and made landfall with the estimated intensity of at least 165 km/h. All global models forecasted Nargis' landfall time early and underestimated its intensity. This entailed some studies using high-resolution limited-area models to predict Nargis's track and intensity. The crucial point here is how to produce the best initial condition for model running. In this study, some data assimilation experiments based on the Local Ensemble Transform Kalman Filter - LETKF (Hunt et al., 2007) were performed to investigate this problem.

Data assimilation and LETKF

In numerical weather prediction, data assimilation is a common name for all methods that combine statistically observations and short-range forecasts from models to produce the best estimate of atmospheric state. The basic idea of data assimilation is similar to the one of Kalman filter when a forecast is adjusted every time new observations are available. In fact, many variants of Kalman filter were used in data assimilation.

LETKF belongs to ensemble-based Kalman filter family. It estimates the first and second moments of probability distribution function (pdf) of atmospheric state from a sample of atmospheric states, which is called an ensemble. The model will propagate these moments in time by integration of each member in the ensemble. By this way, we can estimate the pdf of atmosphere state in future from the current estimation. The use of Bayes' theorem in conjunction with observations in future will reduce the uncertainty related to this new estimation.

NHM-LETKF

The NHM-LETKF system originally developed in Japan Meteorological Agency - JMA (Fujita et al., 2009) was adopted and modified for this study. Since this system was intended for running in the HITACHI supercomputers in JMA, all source codes involving HITACHI machines were modified so that the system can be run in any platforms. The numerical weather prediction model NHM (Saito et al., 2007) was used as the driving model in this system.

The ensemble part of NHM-LETKF consumes the most computational resource in running since we need to run NHM for each member of ensemble. In the original NHM-LETKF system, this ensemble part was not parallelized and forecast members were run sequentially though each NHM model is parallelized. To accelerate the running speed of whole system, this ensemble part of NHM-LETKF was parallelized. To reduce the running time further, the interface programs between NHM and LETKF module were also parallelized. The philosophy here is similar to the one applied for the ensemble part of NHM-LETKF when the input and output of each member were processed in parallel (the output from each member are supplied for LETKF program and LETKF program produces the input for each model).

For the purpose of TC forecast, some new features were incorporated into the system:

- Mercator projection: the quality control part of this system only supports Lambert projection.
- Sea surface temperature (SST) perturbations: SST analyses from 7 centers (FNMOC, JMA, JPL, NCDC, NCEP, REMSS, UKMO) were introduced to consider uncertainty of SST and prevent underestimation of forecast error in the lower atmosphere.
- Running In Place - RIP: use of Ensemble Kalman smoother as a preconditioner. This algorithm was implemented to reduce the spin-up time of system when TCs exist in the analysis domain.
- Assimilation of TC advisories: TC location and minimum center pressure information was assimilated.

Experiments

This study used 50 members to sample the covariance of atmospheric state. Each member shared the same domain with 40 vertical levels and 201x161 horizontal grid points at 20 km resolution (Fig. 1). The assimilated observations included conventional data (surface stations, ships, buoys, aircrafts, radiosondes), satellite-derived winds, sea winds and retrieved precipitable water. The system was run from 12UTC-28/04/2008 to 12UTC-30/04/2008. Then the resulting analysis was used as the initial condition for the next 60-hour NHM forecast. This extended forecast was applied for the same domain however at higher resolution (5 km).

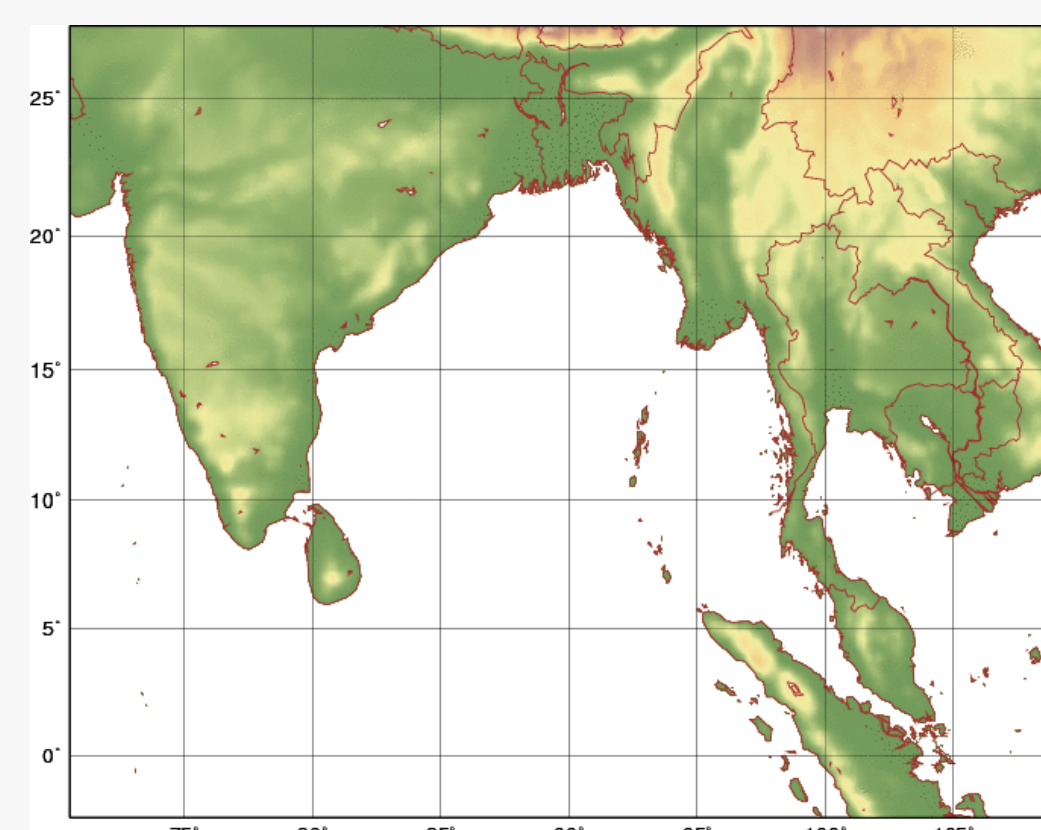


Figure 1: Analysis domain

We performed 3 experiments: LETKF as-is (LETKF), LETKF with the assimilation of TC advisories (LETKF_TC) and LETKF using both RIP and assimilation of TC advisories (LETKF_TC_RIP). SST perturbations were applied for all experiments. Verification was performed using the observation track data from the Regional Specialised Meteorological Center - Tropical Cyclone, New Delhi.

The running time was approximately 30 minutes for each member if 225 nodes were requested for 60-hour forecast in the K Computer. That means the total running time would be 30*50 = 25 hours if the ensemble was run in sequential mode. As a result of parallelization, by using the bulk-job utility, the running time was approximately reduced by a factor of 17, when 17 members were integrated at the same time in a bulk-job (nearly 4000 nodes were requested in K Computer).

Results

Fig. 2 shows simulated infrared satellite images from forecasts initialized with analyses from these experiments. To see the impact from NHM-LETKF, the forecast initialised by interpolation from GSM analysis (GSM_downscaling) and the observation were also plotted.

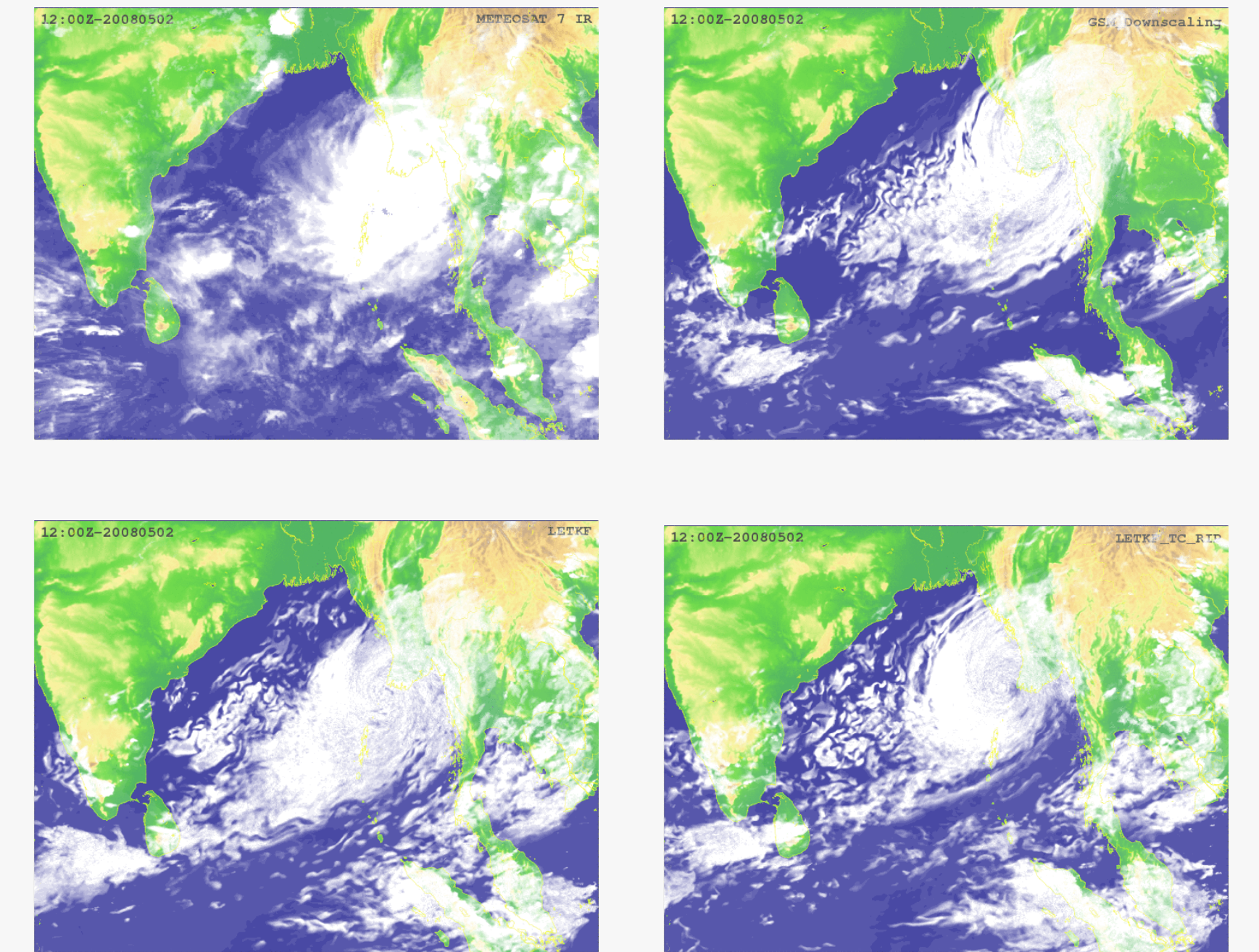


Figure 2: The observational and simulated infrared satellite images by NHM forecasts at Nargis' landfall time

The track and intensity forecasts are shown in Fig. 3. It is clear that the track of GSM_Downscaling has a northern bias with the landfall time of 12-hours before the actual time while LETKF as-is shows a southern bias and the landfall time 12-hours later. The failure of LETKF as-is in producing a better forecast track may be attributed to the lack of observations over the Bay of Bengal.

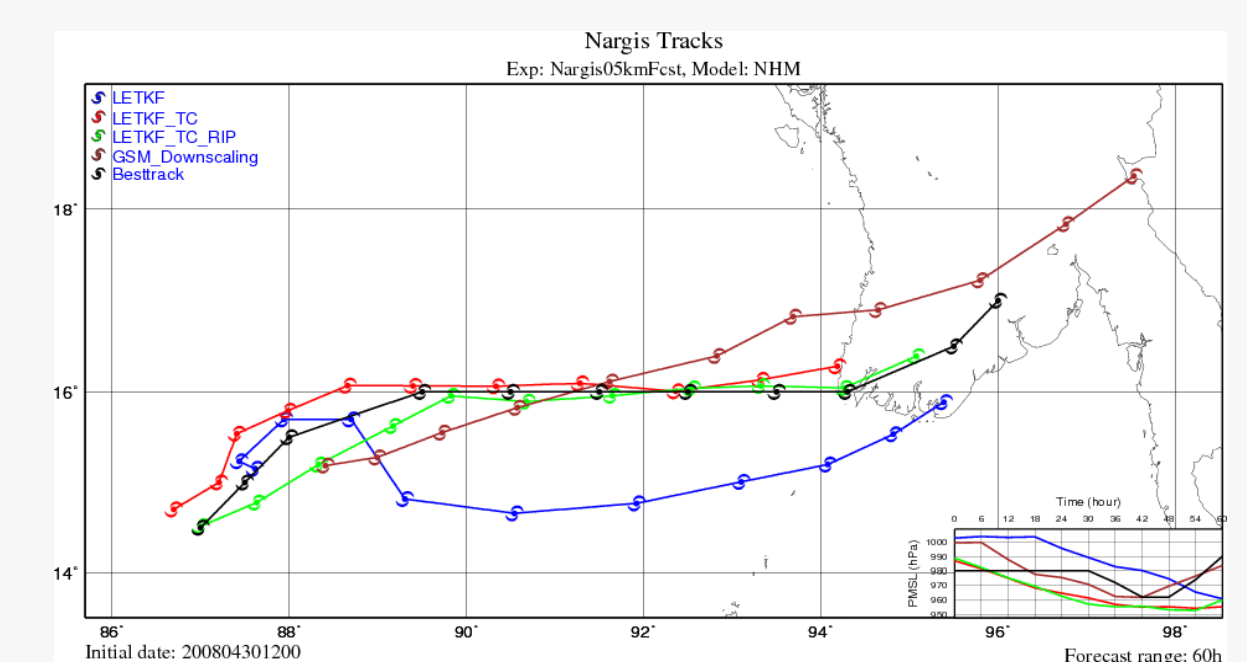


Figure 3: Nargis's track and intensity forecasts with different experiments

When the TC advisories were assimilated, the initial location of Nargis was improved considerably. The forecasted tracks thus are closer to the best track. Especially, when combined with RIP, LETKF_TC_RIP produced the best result among 4 experiments both in track and intensity forecast.

Conclusion

A data assimilation experiment based on NHM-LETKF was conducted to investigate the severe storm Nargis track and intensity forecast. The system were improved both in computational and scientific aspect for the purpose of tropical cyclone forecast. The result showed a better forecast both in tracks and intensities in comparison with the one downscaling from JMA global model or the one initialized by LETKF only.

References

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